3D microfabrication using ultrafast lasers

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1. Introduction

- When an ultrashort pulse of sub-bandgap radiation is focused inside a transparent material, optical energy can be deposited in the material placed at the focal region through various nonlinear absorption mechanisms.

- The deposition of optical energy may induce a localised modification to the material structure, which can manifest itself in a variety of ways e.g. refractive index change, increase in chemical etch-rate.

- Using the manifestations of the laser induced modification, ultrafast laser inscription can be used to directly inscribe three-dimensional structures such as optical waveguides, micro-fluidics, micro-mechanics and micro-optics by translating the material through the laser focus (see Fig. 1).

- This poster presents selected key results from our work in the area of ultrafast laser micro-fabrication.

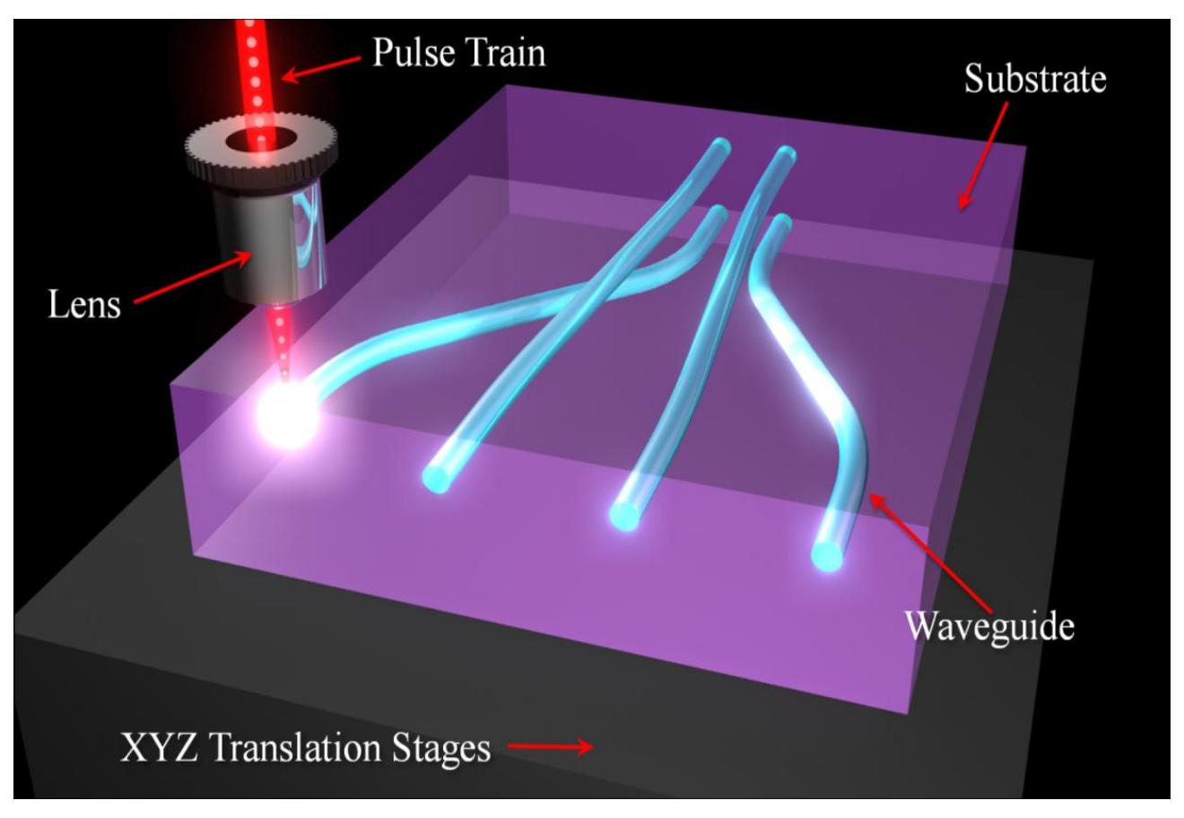

Fig. 1 Cartoon of the ultrafast-laser inscription process

2. Multicore fibre interconnects

Motivation – Multicore optical fibres (MCFs) are finding applications in many fields e.g. sensing. Due to the close proximity and arrangement of the cores, the coupling of light to and from MCFs can pose a significant problem. An integrated three-dimensional interconnect device that enables the coupling of light to and from MCFs with any core geometry would be an enabling technology for the development of real-world MCF applications.

Multicore fibre coupler development

- Using ultrafast laser inscription, we have fabricated a three-dimensional interconnect device which enables each core of a 2 × 2 core array MCF (see Fig. 2) to be addressed individually by one of four single mode fibres held in a 4 × 1 fibre V-groove array, as shown in Figs. 3 & 4 Recent studies indicate interconnection losses <1.0 dB are readily achievable and that the technology can be used for MCFs consisting of > 100 cores.

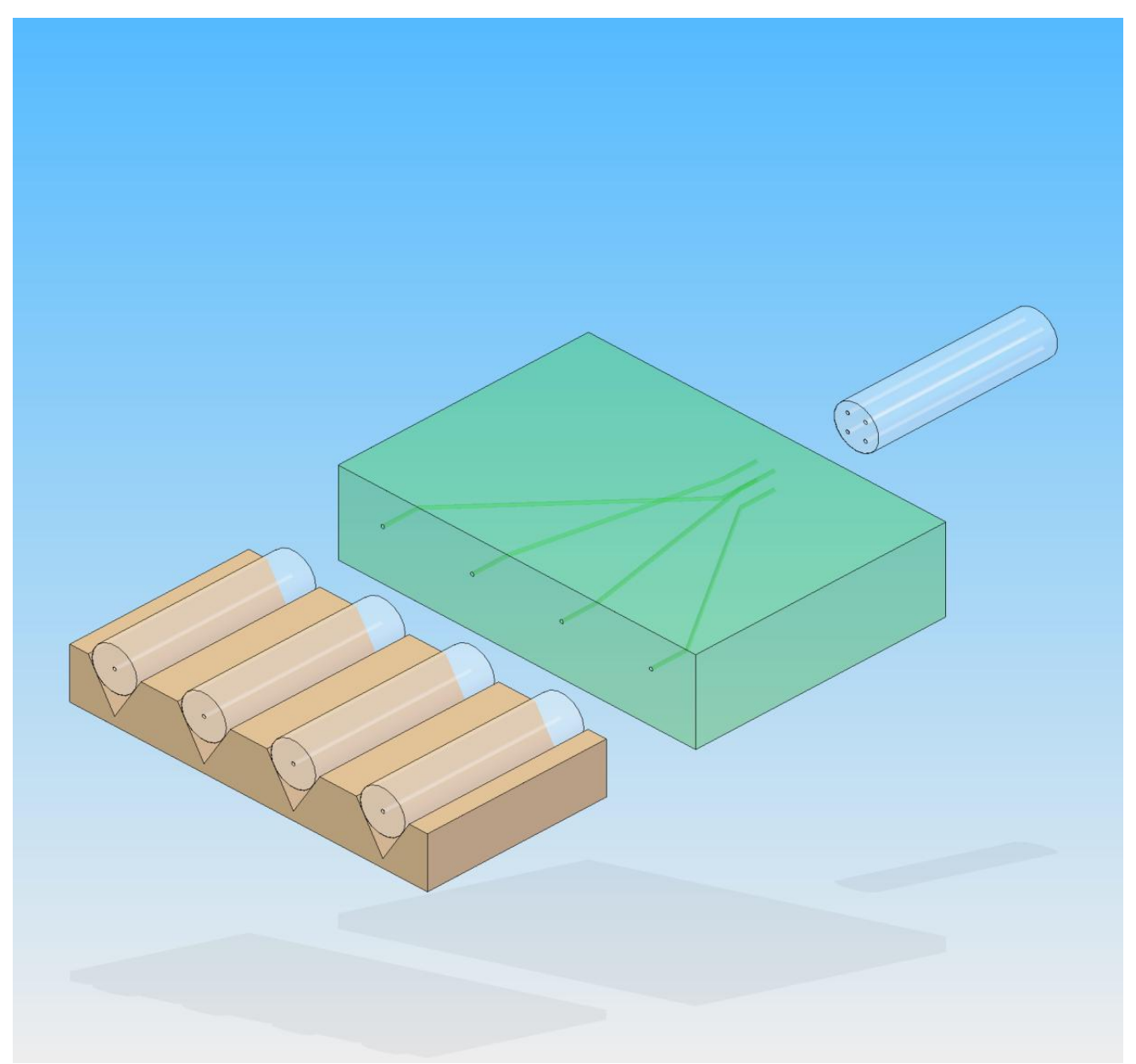

Fig. 3 Conceptual diagram of the MCF interconnect implementation.

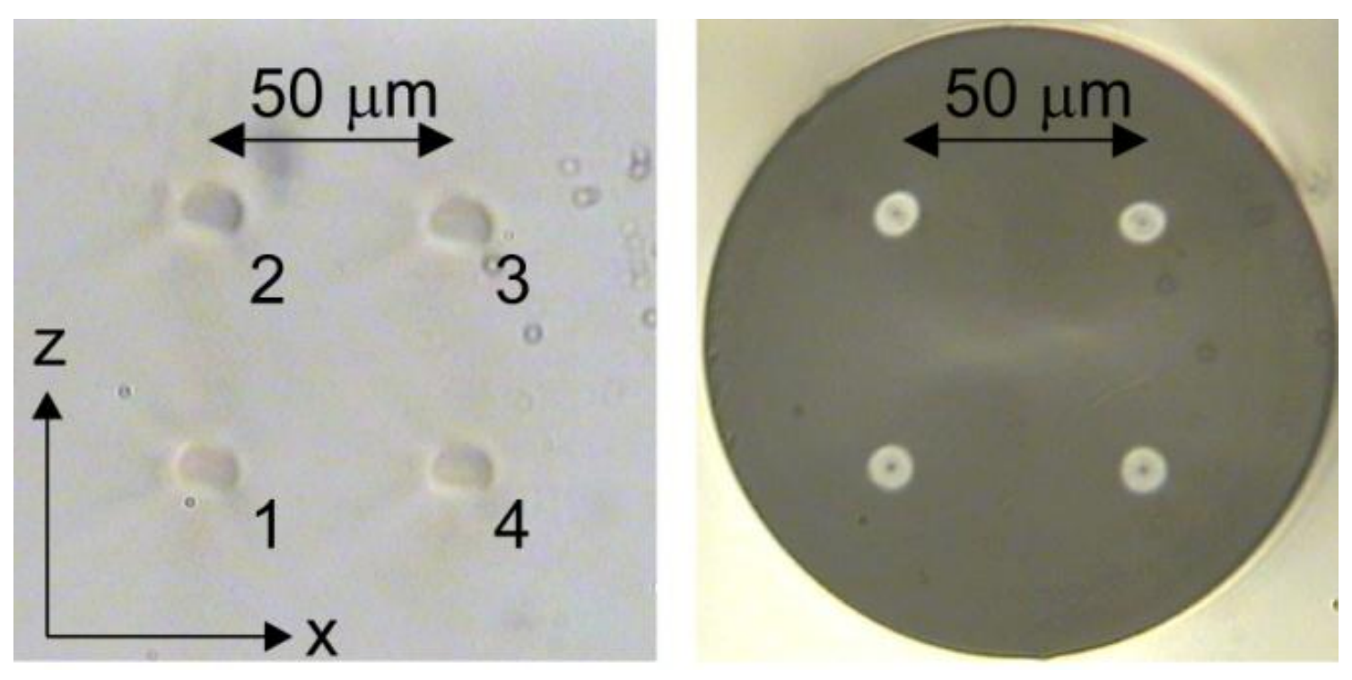

Fig. 2 Micrographs of (left) the MCF coupling end of the interconnect and (right) the MCF itself.

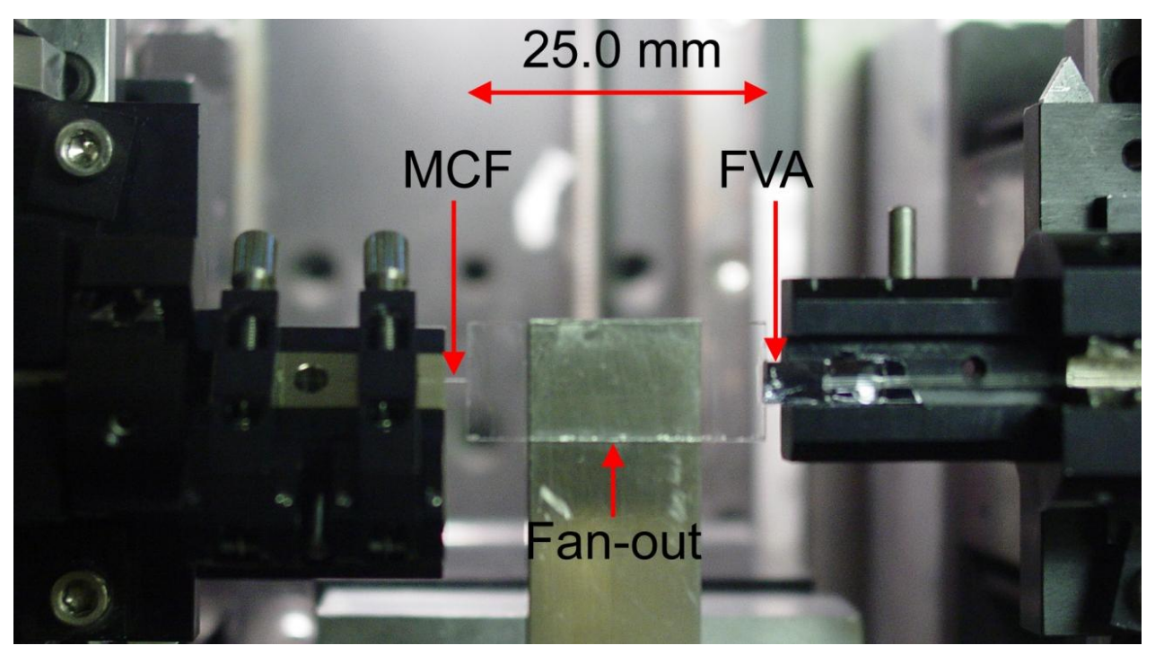

Fig. 4 Photograph of the interconnect being used to connect to the MCF.

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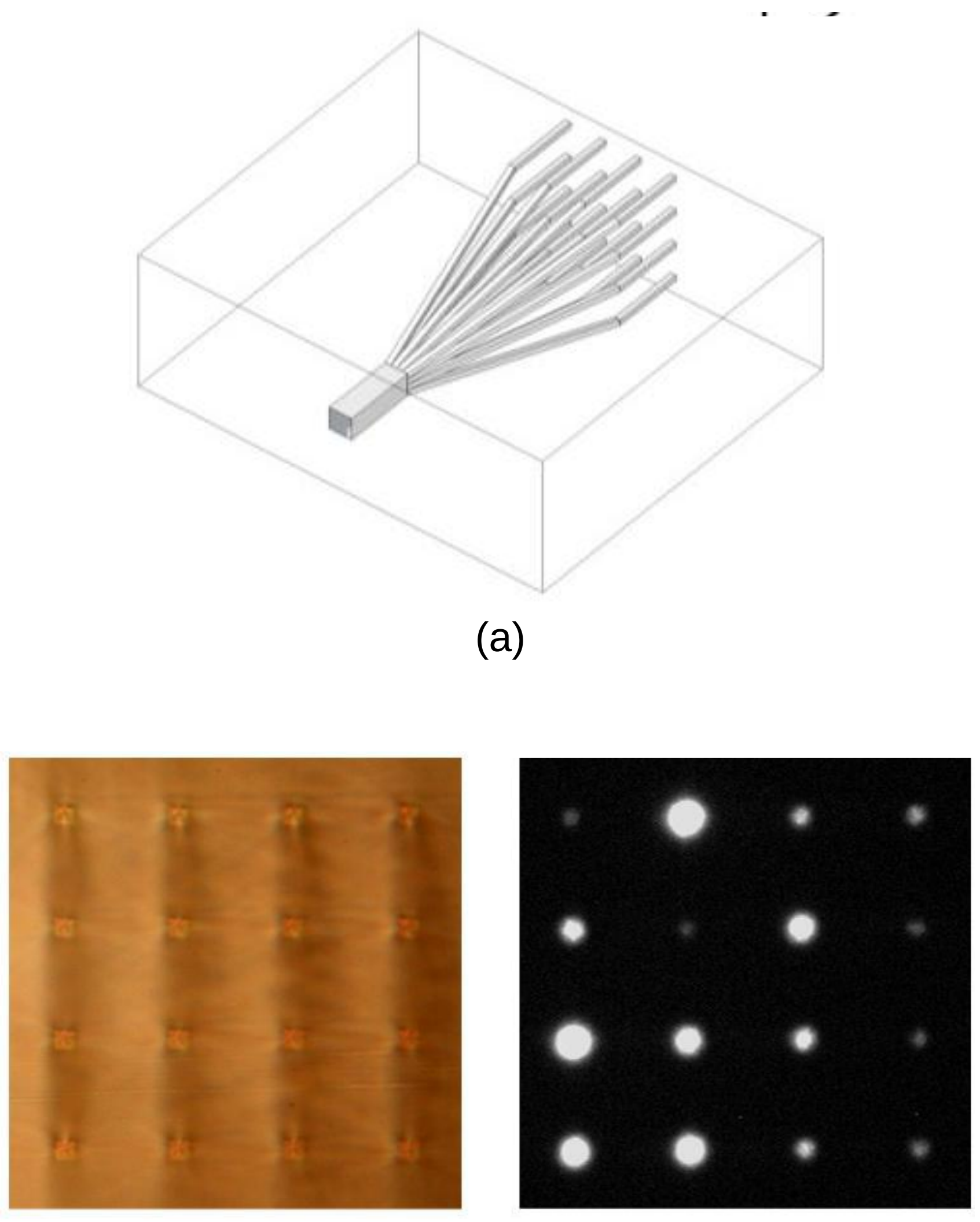
3. Astrophotonics

Motivation – The era of the extremely large telescope (ELT) has arrived and there is now a drive to develop the required instruments. Old instrumentation technologies do not scale favourably – both in terms of function and cost. To break the scaling laws, we are applying photonic concepts to develop astrophotonic instrumentation which will outperform traditional instrument technologies.

Integrated photonic lantern development

- It is often essential to collect the light from the telescope using a highly multimode fibre, due to low-photon fluxes. This poses a problem for astrophotonics, since many photonic technologies (e.g. fibre Bragg-gratings) only operate efficiently on single mode light. To overcome this issue, the photonic lantern has been developed which facilitates the low-loss coupling of light between a multimode fibre and an array of single modes.

- We have used the three-dimensional optical waveguide fabrication capability of ultrafast laser inscription to realise the first integrated photonic lantern, shown conceptually in Fig. 5(a). This device facilitates the low-loss (<2.0 dB) coupling of multimode light into single mode photonic devices, as shown in Figs. 5(b) and (c).



(a)

(b) (c)

Fig. 5 (a) Sketch of the integrated photonic lantern. (b) Micrograph of the single mode waveguide output array (b) near field image of the output array when injecting 1.55 μm light into the multimode end of the device.

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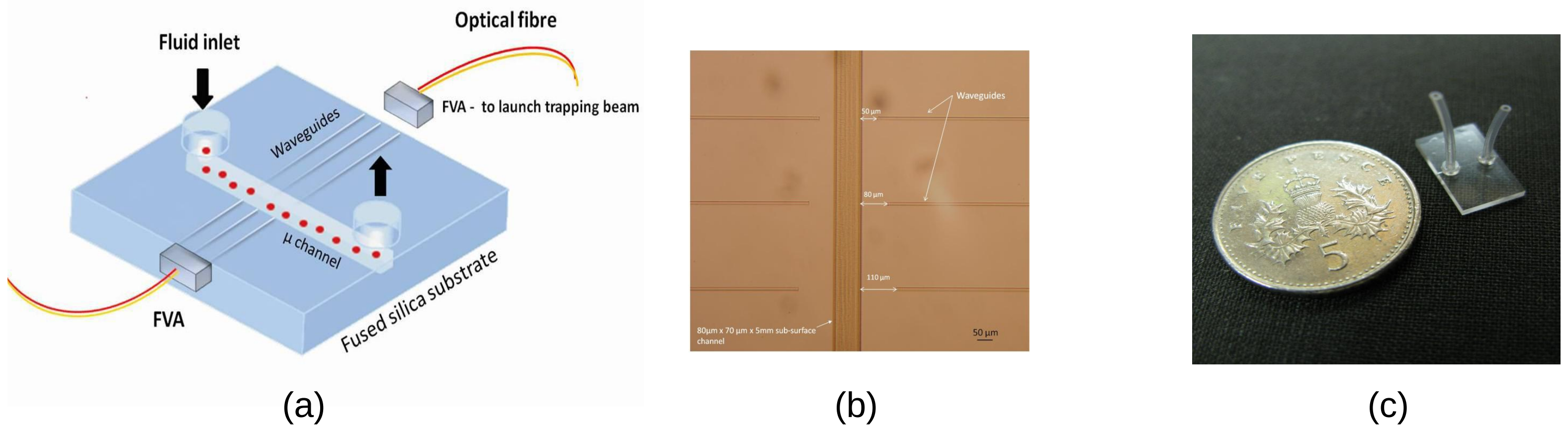
4. Biophotonics

Motivation – Ultrafast laser inscription facilitates the integration of microfluidics with integrated optics and micro-optics. This capability is extremely powerful for the development of highly functional custom lab-on-a-chip devices. We are using this capability to develop lab-on-a-chip devices for applications such as cell sorting, trapping and optical stretching.

Integrated cell-stretcher development

- Using ultrafast laser inscription we are able to selectively increase the chemical etch-rate of fused silica. As shown in Fig.6, we successfully used this capability to integrated a sub-surface micro-fluidic channel with an array of optical waveguides.

- We have used the device shown in Fig. 6 to optically trap micro-spheres and we are working towards optically trapping and stretching living cells. These devices may find applications in fundamental research, but also in areas such as cancer diagnosis and drug screening.



(a) (b) (c)

Fig. 6 (a) Cartoon of the proposed integrated optical cell-stretcher. (b) Photograph of the sub-surface micro-fluidic, with the optical waveguides intercepting the channel. (c) Photograph of the connectorised integrated optical-cell stretcher next to a UK 5 pence piece for scale.

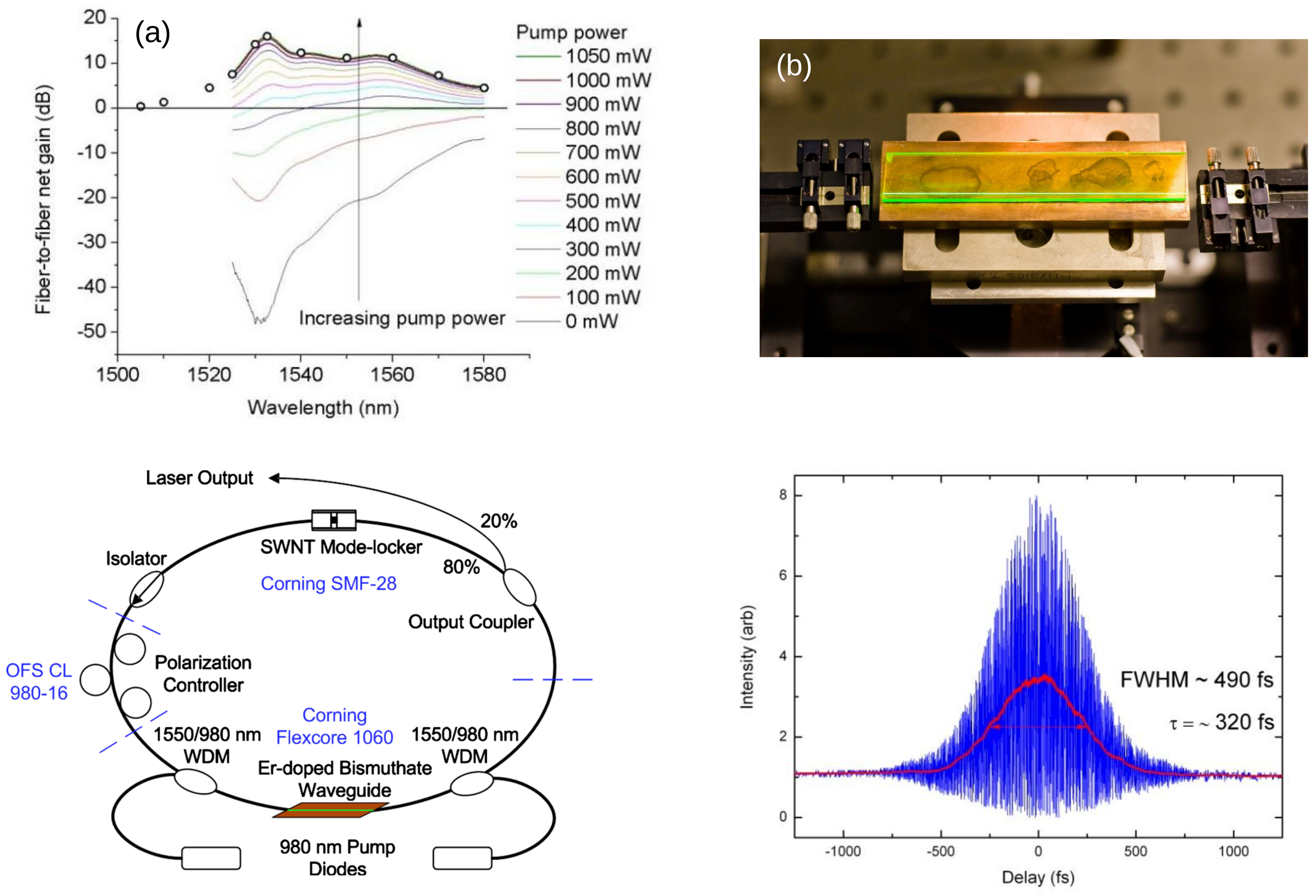
5. Active waveguide devices

Motivation – There is currently a demand for compact, high-repetition rate mode-locked laser sources for applications in areas such as optical metrology, nonlinear microscopy and astronomy. The material flexibility of ultrafast laser inscription makes it ideally suited to the development of compact active waveguide devices such as laser sources.

Mode-locked Er-doped waveguide laser development

- An Er-doped bismuthate glass amplifier was fabricated by inscribing a waveguide in a 90 mm long Er-doped bismuthate glass sample. Fig 7(a) presents the net gain spectra measured for the amplifier under different pump powers. The amplifier exhibited a maximum net gain of ≈ 17.0 dB. When factoring in the 4.0 dB background insertion loss, this equates to a ≈ 2.3 dB/cm peak internal gain.

- As shown in Fig. 7(c), a ring-cavity was constructed around the waveguide amplifier. The cavity consisted of a carbon nano-tube saturable absorber developed at the University of Cambridge. As shown in Fig. 7(d), the laser emitted 320 fs pulses which were close to bandwidth limited. The pulse repetition frequency was 40 MHz, the central wavelength was 1.56 μm and the average output power was 1.25 mW. This represents the demonstration of the first fs-laser fabricated using ultrafast laser inscription.



(c) (d)

Fig. 7 (a) Net gain spectra measured at different pump powers for the 90 mm long Er-doped bismuthate waveguide amplifier. (b) Photograph of the Er-doped bismuthate waveguide under full pumping. (c) Diagram of the mode-locked laser cavity using the Er-doped waveguide amplifier and a carbon nano-tube saturable absorber. (d) Autocorrelation of the ultrashort pulses emitted by (c).

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